Tech Memo
AERO 2228

DEFENCE RESEARCH AGENCY
AEROSPACE DIVISION

Technical Memorandum

December 1991

The 13ft x 9ft Low Speed Wind Tunnel Facility at DRA (Aerospace Division) Bedford (UK)

by

M. N. Cripps

RAE, Bedford, Bedfordshire

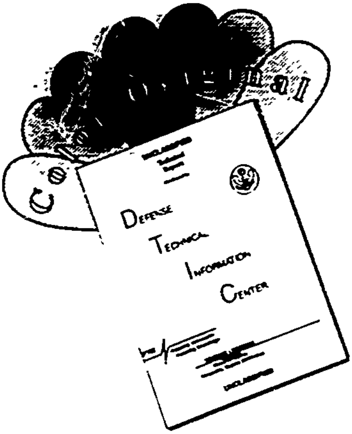
0120196 CONDITIONS OF RELEASE 308898

************************** DRIC U

************************** DRIC Y

Reports quoted are not necessarily available to members of the public or to commercial organisations.

DISCLAIMER NOTICE



THIS DOCUMENT IS BEST QUALITY AVAILABLE. THE COPY FURNISHED TO DTIC CONTAINED A SIGNIFICANT NUMBER OF COLOR PAGES WHICH DO NOT REPRODUCE LEGIBLY ON BLACK AND WHITE MICROFICHE.

DEFENCE RESEARCH AGENCY

Aerospace Division

RAE Bedford

Technical Memorandum Aero 2228

Received for printing 4 December 1991

THE 13ft x 9ft LOW SPEED WIND TUNNEL FACILITY AT DRA (AEROSPACE DIVISION) BEDFORD (UK)

by

M. N. Cripps

SUMMARY

This paper describes the DRA (Aerospace Division) 13ft x 9ft (4m x 2.7m) Low Speed Tunnel at RAE Bedford. It is intended to provide an introduction to the capabilities of this comprehensive test facility for speeds of up to 90 ms^{-1} at atmospheric pressure

LIST OF CONTENTS

1 INTRODUCTION

Fig 1 shows the RAE Bedford 13ft x 9ft Low Speed Tunnel which was commissioned in 1954 to provide a low turbulence test facility. It is a closed-circuit atmospheric tunnel with a maximum airspeed of 90 ms^{-1}. The tunnel provides an ideal low speed research facility for both full and half-models, with a range of support options for sting and strut mounted full models or floor mounted half-models. Static and dynamic measurements can be made, along with a variety of flow visualisation techniques, such as liquid crystals, laser illuminated smoke screens and micro-tufts. The tunnel has a fast start-up and shutdown time, requires minimal supervision by the user and has relatively low operating costs.

2 TUNNEL CIRCUIT

Fig 2 shows the tunnel circuit which is rectangular in planform. The major legs are 100 m long and the shorter legs 20 m long, giving a total circuit length of 240 m. Most of the tunnel shell is made from reinforced concrete with the interior of the walls smoothed down to provide minimum resistance to the air flow. Guide vanes are provided at each corner. Great care has been taken throughout the design of the tunnel to ensure the very highest standards of flow quality.

The diffuser angle is 5° and 8 vortex generators are evenly distributed at the upstream end, inclined at 12° to the airstream, to improve the uniformity of velocity distribution across the working section. The octagonal settling chamber is 14 m across, giving a contraction ratio to the working section of 16:1. Four turbulence reducing screens are fitted.

The working section, shown in Fig 3, is timber lined in a steel frame. The airstream is 4 m wide and 2.7 m high with 0.6 m wide corner fillets. It has been established that in a 1.8 x 1.8 m^2 reference plane normal to the airflow in the working section the longitudinal turbulence levels are better than 0.025% and the lateral levels 0.095% at full speed. The roof and floor are fitted with turntables about 3 m in diameter which revolve around a common axis through the tunnel centre. Windows in the roof and walls of the working section allow visual observation and provide for laser light sheet projection. The entire wall on one side of the working section opens out for easy access during rigging. Downstream of the working section are 2 braking flaps which normally lie flush in the roof and floor, but when deployed rapidly reduce the airflow to rest for a quicker shutdown.

A 1.1 MW ac motor with a solid state variable frequency supply system drives a 9.3 m diameter 6 bladed fan at a maximum speed of 330 rev/min. Automatic control of the fan using the relationship between the pressure in the working section and the settling chamber provides an air speed setting which is constant to within 0.1%.

3 AIR SUPPLIES

High pressure air is available for jet or turbine power simulation experiments. The air supply is at a pressure of 4.5 MPa and passes through a regulator, a 140 kW electric heater and an orifice plate. Air of known temperature and mass flow can be delivered to the model. A typical flow rate would be 4.5 kgs^{-1} at 2.9 MPa. Over 91 m^3 of air is stored at 26 MPa and recharged at 1.5 kg^{-1}.

For lower pressure work two 970 kW pumps are available providing a total flow of 4.5 kg^{-1}. This can be used for suction or blowing in boundary layer control or similar experiments.

4 MECHANICAL FORCE BALANCES

The overhead mechanical balance measures the 3 forces and 3 moments on a model. Either wire rigs or, as in Fig 4, support struts with non-metric fairings may be used. A nose or tail wire connects to the overhead pitch beam and down to a ballast weight beneath the floor, which can be immersed in oil to provide damping to the support system. The automatic incidence range is –10° to +40° with no restriction on yaw. Table 1 shows that two loading ranges are available for each component. The resolution is 10 ppm.

The underfloor balance is a smaller mechanical balance mounted below the floor of the lower turntable when required. It is primarily designed for half-model tests as illustrated in Fig 5. The balance does not measure side force or yaw. The figures in Table 2 indicate the load range. Again, two loading ranges are available for each component and any combination can be used. Resolutions is of the order 50 ppm.

Both these mechanical balances are self balancing and provide extremely accurate force data with very little interaction between channels. On-line analysis of balances can provide non-dimensional coefficients in balance axis, body axis or wind axis.

The dynamic balance, shown in Fig 6, is a relatively thin sandwich of load cells between two steel plates and may be inserted between the model and the underfloor mechanical balance. This balance combines the output of the piezo-electric load cells at each corner of the plate to give six components of force over a frequency range 0 to 200 Hz. It has a normal force range of ±5 kN and a maximum pitching moment of 1.6 kNm. Time dependent data from this balance and other transducers can be analysed using the RAE Presto signal processing system.

5 STING MOUNTING RIGS

5.1 Pitch and height

The pitch and height rig, shown in Fig 3, is used for most sting mounted models. It has a pair of differentially driven vertical lead screws which allow independent control of model pitch and height. In addition the entire rig is mounted on the lower turntable to allow model yaw to be varied over the range ±22°. The pitch range is ±17° and several different sting crank-angles can be used to increase this. The height can be varied over the full range limited only by the proximity of the model to the roof and floor. A 5 cm diameter high-pressure air pipe may be used with this sting rig for jet exhaust experiments. Various swivel joints allow the pipe to cope with the movement of the model on the rig.

5.2 High incidence

The high incidence rig is very stiff and may be used with conventional sting mounted models but is very well suited to oscillatory or rotating model experiments, as shown in Fig 7. The large quadrants allow a ±90° pitch range. It is mounted between the turntables to allow yaw, though the travel is limited due to blockage considerations.

5.3 Wake traverse

The wake traverse rig allows a probe to be moved around in the vicinity of the model in 3 orthogonal axes. An alternative use for this rig is the controlled drop of a store from beneath a wing. The good view of the working section is particularly welcome for this work.

5.4 Missile

A missile rig is available which connects between the top and bottom turntables. The turntables can be moved together to give model yaw and the rig will also roll the model.

6 SPECIAL MOUNTING RIGS

6.1 Free to yaw

The free-to-yaw rig is used with light-weight models and consists of a pillar attached to the centre of rotation of the lower turntable. A spline at the top fits into a bearing in the underside of the model. The model is free to move in the yaw plane, but held at a fixed pitch angle.

6.2 Ground board

For ground effect testing a fixed ground board with boundary layer suction can be fitted in the floor of the tunnel.

6.3 Rotary sub-rig

For spinning models a rotary sub-rig can be mounted on the high incidence rig to measure high incidence dynamic behaviour.

7 STRAIN GAUGE BALANCES

A range of strain gauge balances is available for measuring the 3 forces and 3 moments on a sting mounted model. Fig 8 shows an example. Depending on the load 57, 51 or 25 mm diameter balances are used. Table 3 shows the range of strain gauge balances available.

The balances are calibrated against a precision 6 degree of freedom loading machine to give sensitivities and interaction matrices. A considerable inventory of weights, loading frames and pulleys are available for in-stream balance calibration. On-line analysis of balances can provide non-dimensional coefficients in balance axis, body axis or wind axis.

8 MODEL PRESSURE MEASUREMENT

For model pressure plotting individual or modular pressure-scanning switches can be used. Groups of 48 pressures are measured in turn by a single semiconductor diaphragm transducer in less than 1 minute. Five of the 48 ports are used to calibrate the semiconductor transducer automatically against a pressure standard during each scan to give accurate data. Pressure data is available on-line as coefficients based on dynamics pressure. Facilities for time dependent pressure measurement and signal processing are also available.

9 FLOW VISUALISATION

Flow visualisation using laser vapour screens takes advantage of the large high quality glass windows. A laser fan is projected across the model and smoke or fog is injected into the airstream. Fig 9 shows a very strong image of the vortices around the model at a particular section. Video recordings can be made for later analysis.

Oil-flow techniques are used to visualise the flow patterns on the model surface. Light oils with fluorescent pigment are used and the pattern photographed under ultra-violet light which causes the paint to fluoresce, revealing fine details.

Micro-tufts can be used as an alternative to oil flow. The model surface is covered in a grid of micro-filament tufts which will fluoresce in ultra-violet light. The tufts are small enough not to influence the flow significantly. This technique has the considerable advantage of allowing continuous tunnel running with video recording of the patterns. The

model shown in Fig 10 is spinning on the rig shown in Fig 7 and provides a good example of this technique.

10 TUNNEL DEVELOPMENT

AE3 Division of Aerodynamics Department manage the 13ft x 9ft low speed wind tunnel and the other research facilities at RAE Bedford. There is a programme of continuous improvement to these facilities and particular emphasis is placed on the compatibility of hardware, software and procedures across the three major wind tunnels: the 13ft x 9ft, the 8ft x 8ft and the 3ft x 4ft. This policy ensures that maximum advantage is gained from the resources invested in development, maintenance and management of these three tunnels.

11 RESEARCH FACILITIES AT RAE BEDFORD

RAE's range of experimental facilities at Farnborough and Bedford is one of the largest in Europe. Bedford has an extensive aerodynamic testing capability over a wide range of Mach and Reynolds numbers.

The 13ft x 9ft Low Speed Tunnel for speeds up to 90 ms^{-1} at atmospheric pressure.

The 8ft x 8ft High Speed Tunnel with a Mach number range 0.2 to 2.5 at up to 4 atmospheres.

The 3ft x 4ft High Supersonic Speed Tunnel with a Mach number range 2.5 to 5.0 at up to 11 atmospheres.

The 4ft x 1ft Boundary Layer (Open Return) Tunnel for speeds up to 45 ms^{-1}.

The 4ft x 3ft Low Speed (Open Return) Tunnel for speeds up to 30 ms^{-1}.

The 1ft x 1ft Cryogenic Test Duct for speeds up to 27 ms^{-1} at temperatures down to 90 K.

The 0.7ft x 0.7ft Water Tunnel for study of flows up to 0.15 ms^{-1}.

The Air Blast Test Rig which discharges 3.5 atmospheres through a 76 cm jet nozzle at up to sonic speed.

These are supported by:

Wind tunnel development and instrumentation staff.

Theoretical and experimental aerodynamic research scientists.

Model design, manufacture and inspection capacity in metal, wood and composite.

Computing resources for data processing and computational fluid dynamics.

A precision 6 degree of freedom loading machine for calibrating force balances.

12 THE RAE BEDFORD 13ft x 9ft TUNNEL CHARACTERISTICS

Commissioned	: 1954
Tunnel type	: 240 m return circuit, continuous flow
Contraction ratio	: 16 to 1
Working section	: 4 x 2.7 m^2 rectangular with corner fillets
Power	: 1.1 MW
Pressure	: Atmospheric
Speed	: 0 to 90 ms^{-1}
Reynolds number	: 5.0 x 10^6 m^{-1} max
Turbulence levels	: 0.025% longitudinal at full speed
Air supply	: 4.5 MPa, typical flow 4.5 kg^{-1} at 2.9 MPa
Overhead balance	: 6 component automatic weight-beam
Underfloor balance	: 4 component automatic weigh-beam
Sting rig	: independent model height and incidence
Sting support	: ±90° high incidence rig
Sting balances	: inventory of strain gauge balances
Site location	: 5 kilometres north of Bedford on A6
Contact	: 13ft x 9ft Tunnel Manager DRA (Aerospace Division) Bedford MK41 6AE Tel: (0234) 225990 Fax: (0234) 225848

Table 1

LOADING RANGE OF THE OVERHEAD MECHANICAL BALANCE

COMPONENT	LOAD RANGE		RESOLUTION	
	LIGHT	HEAVY	LIGHT	HEAVY
Axial Force	1.8 kN	4.4 kN	0.02 N	0.04 N
Side Force	±1.8 kN	±4.4 kN	0.04 N	0.08 N
Normal Force	8.9 kN	22 kN	0.09 N	0.2 N
Rolling Moment	±410 Nm	±1000 Nm	0.008 Nm	0.02 Nm
Pitching Moment	±540 Nm	±1400 Nm	0.01 Nm	0.03 Nm
Yawing Moment	±410 Nm	±1000 Nm	0.008 Nm	0.02 Nm

Table 2

LOADING RANGE OF THE UNDERFLOOR MECHANICAL BALANCE

COMPONENT	LOAD RANGE		RESOLUTION	
	LIGHT	HEAVY	LIGHT	HEAVY
Axial Force	1.8 kN	5.3 kN	0.09 N	0.3 N
Normal Force	4.4 kN	13 kN	0.2 N	0.7 N
Rolling Moment	13 kNm	40 kNm	0.4 Nm	1.4 Nm
Pitching Moment	1.4 kNm	4.1 kNm	0.7 Nm	0.2 Nm

Table 3

STRAIN GAUGE BALANCES

BALANCE	L/2/C	L/2/D	2¼L	747	V20	UNITS
Axial Force	450	670	670	90	1100	N
Side Force	1100	1100	1600	670	1600	N
Normal Force	3100	3100	7100	670	1600	N
Rolling Moment	120	120	240	70	190	Nm
Pitching Moment	340	340	750	200	2300	Nm
Yawing Moment	120	120	240	200	2300	Nm

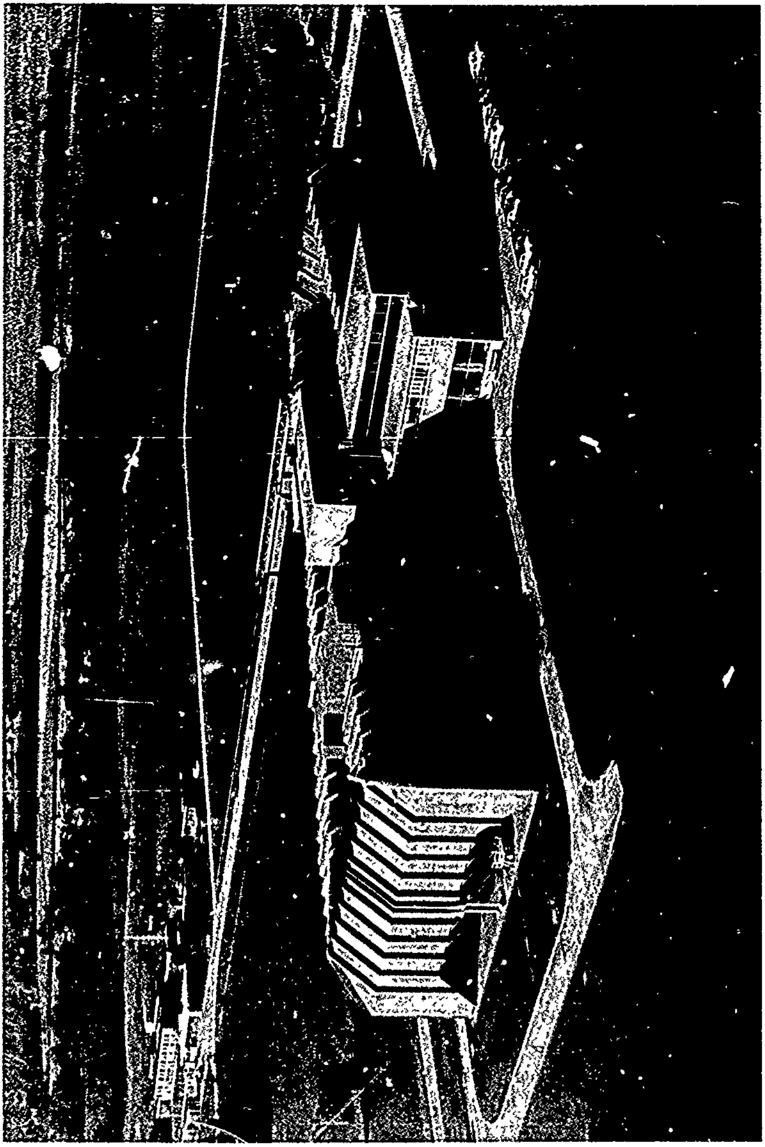


Fig 1 The 13ft x 9ft Low Speed Tunnel at DRA Bedford

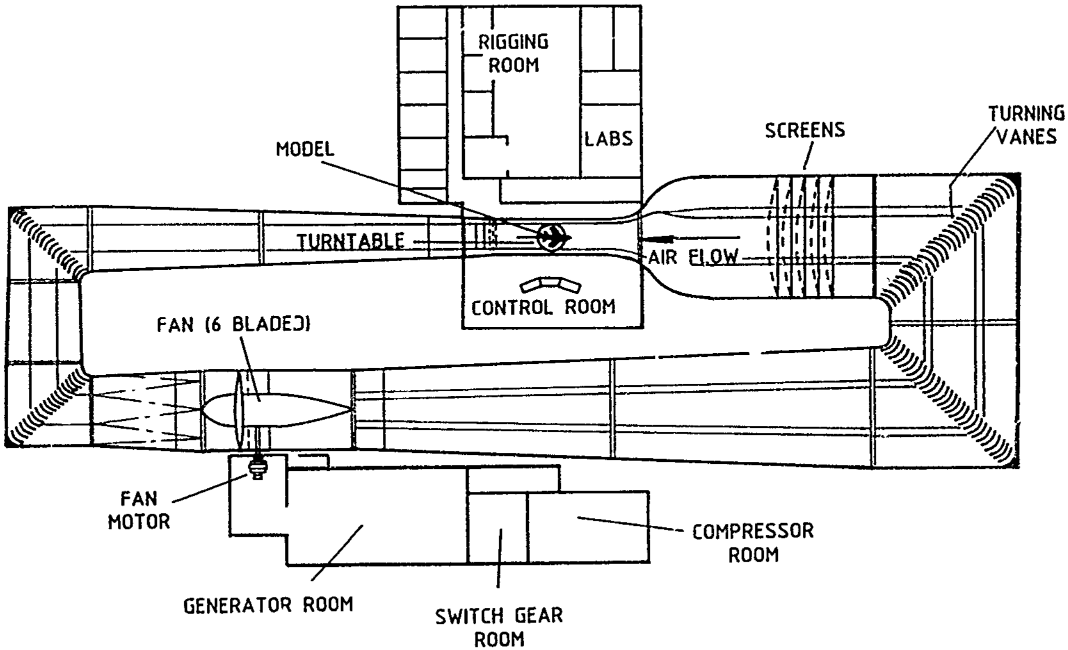


Fig 2 Plan view of the 13ft x 9ft Low Speed Tunnel

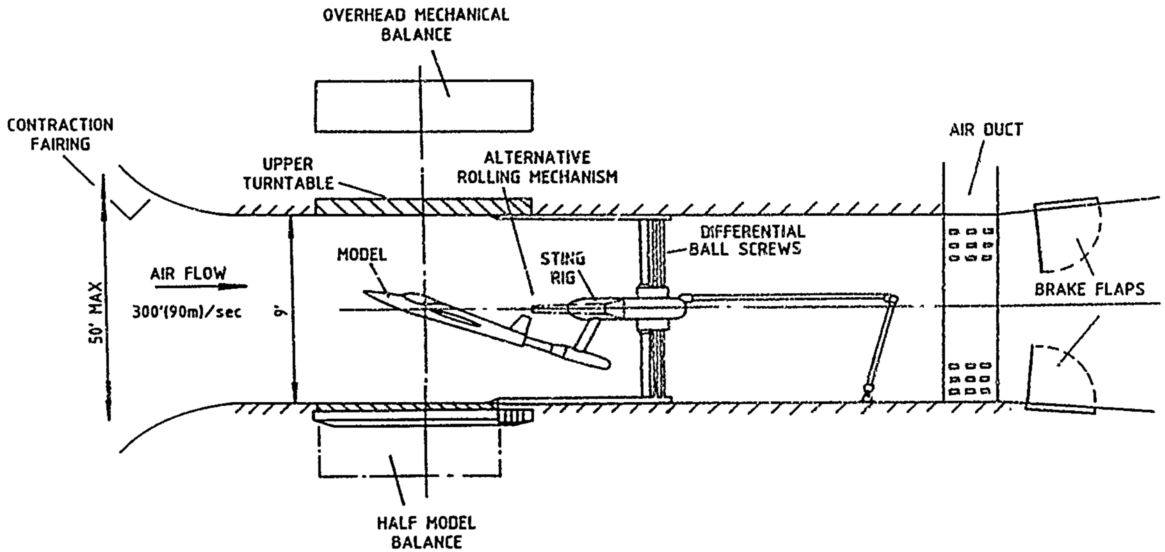


Fig 3 The 13ft x 9ft working section and model mounting facilities

Fig 4 Model mounted on overhead mechanical balance turntable using struts

Fig 5 Half-model mounted on underfloor mechanical balance and turntable

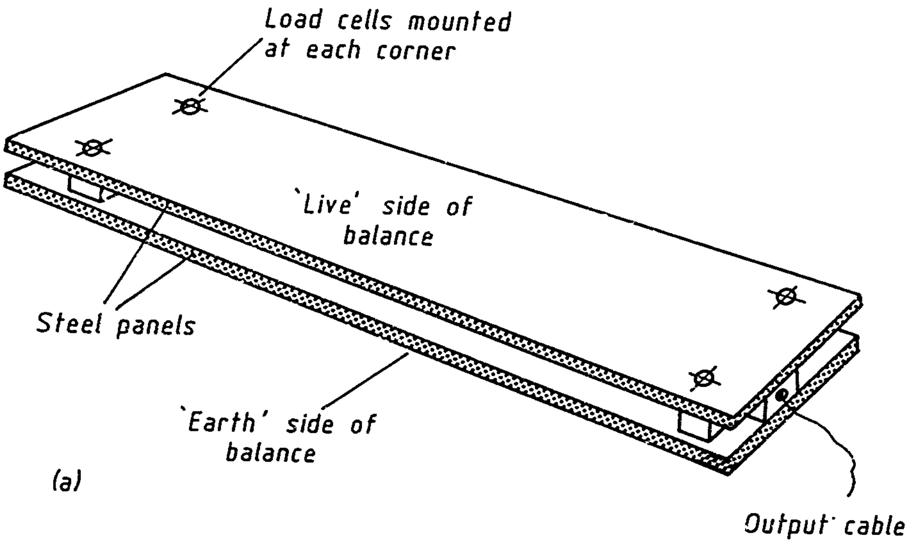


Fig 6 Six component dynamic balance for use with half-models

Fig 7

Fig 7 Spinning model on High Incidence Rig

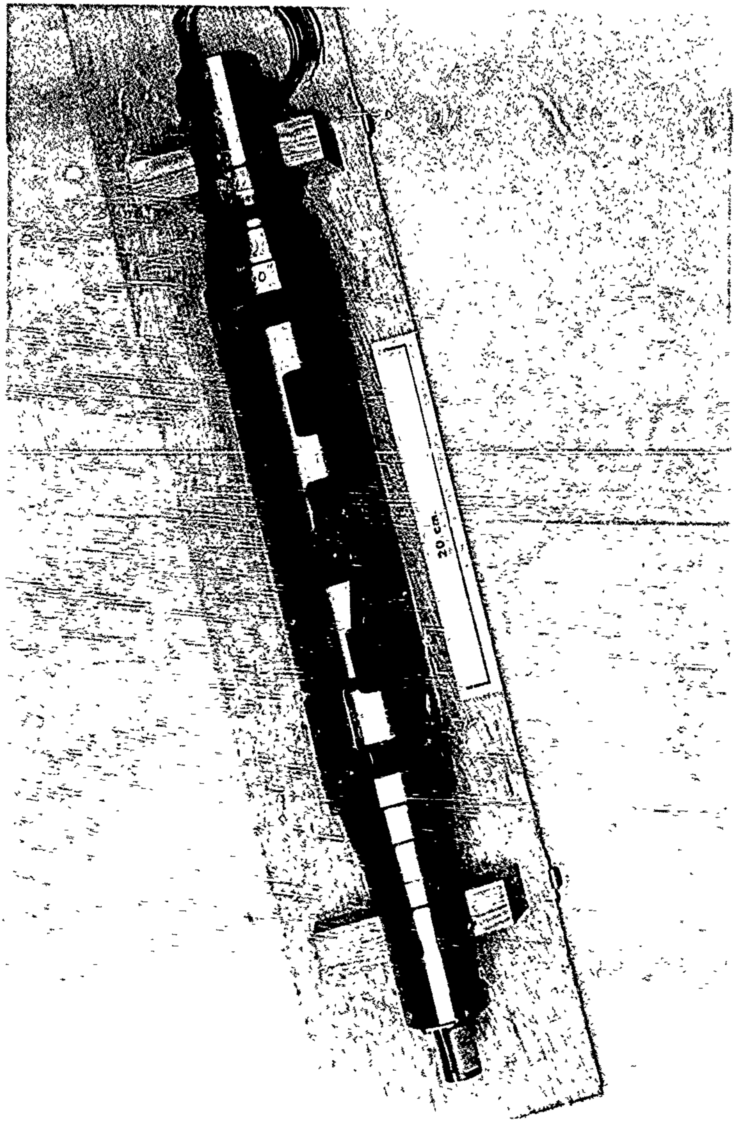


Fig 8 Six component strain gauge balance for string mounted models

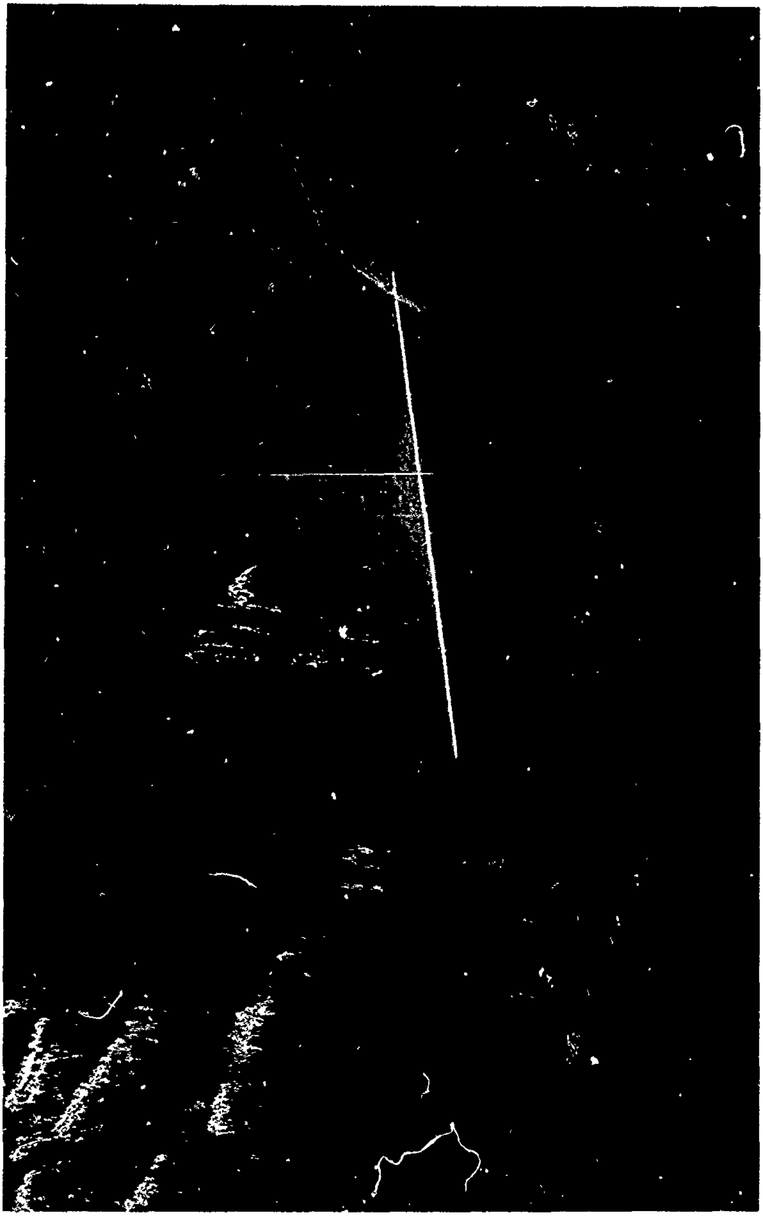


Fig 9 Vortex imaging by laser vapour screen

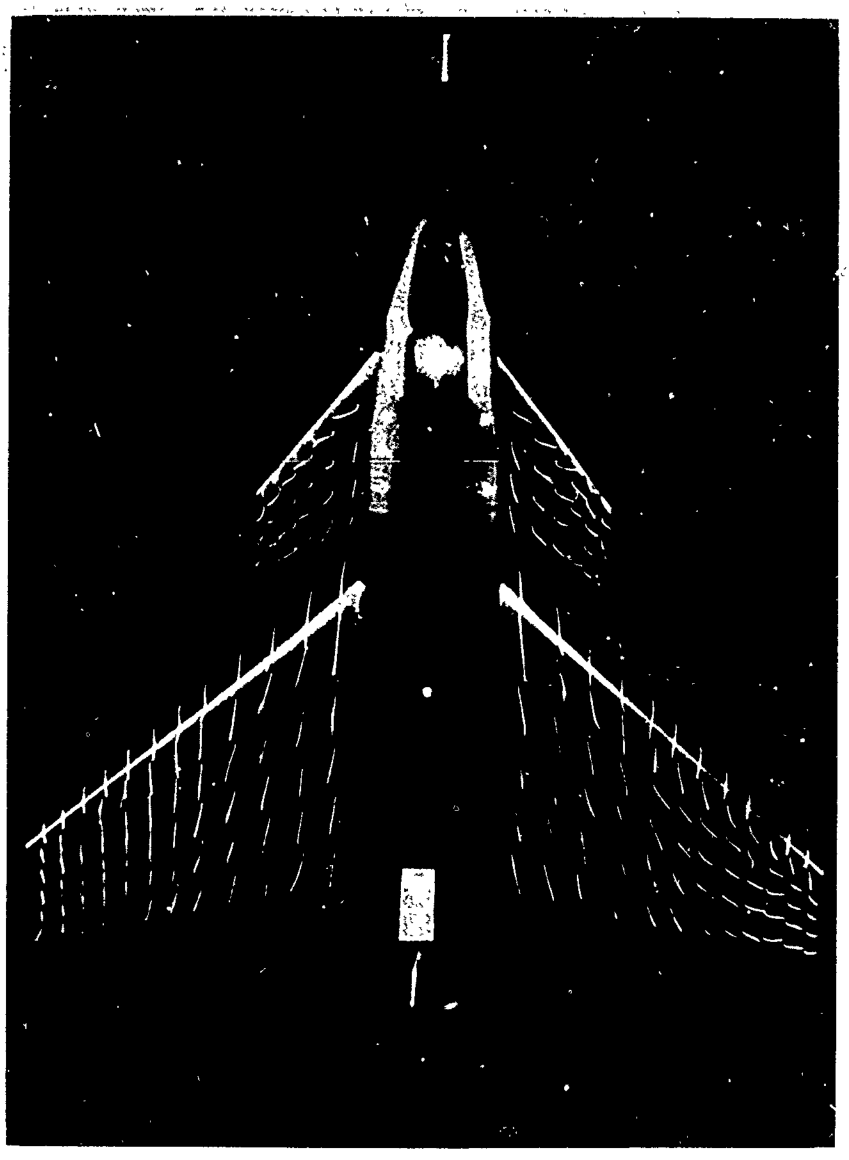


Fig 10 Flow visualisation using micro-tufts

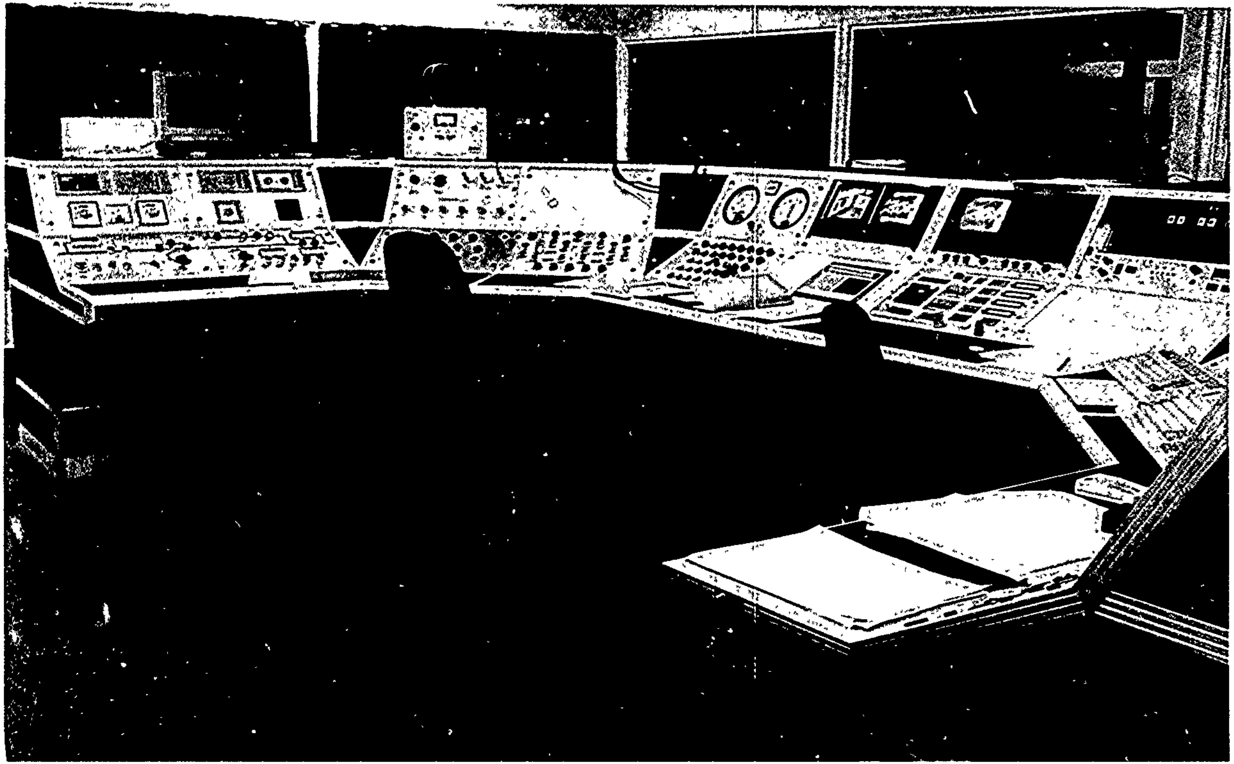


Fig 11 The 13ft x 9ft Low Speed Tunnel control and observation room

REPORT DOCUMENTATION PAGE

Overall security classification of this page

UNLIMITED

As far as possible this page should contain only unclassified information. If it is necessary to enter classified information, the box above must be marked to indicate the classification, e.g. Restricted, Confidential or Secret.

1. DRIC Reference (to be added by DRIC)	2. Originator's Reference	3. Agency Reference	4. Report Security Classification/Marking
	RAE TM Aero 2228		UNLIMITED

5. DRIC Code for Originator	6. Originator (Corporate Author) Name and Location
7672000H	DRA Aerospace Division, RAE, Bedford, Beds, UK
5a. Sponsoring Agency's Code	**6a. Sponsoring Agency (Contract Authority) Name and Location**

7 Title The 13ft x 9ft low speed wind tunnel facility at DRA (Aerospace Division) Bedford (UK)

7a. (For Translations) Title in Foreign Language

7b. (For Conference Papers) Title, Place and Date of Conference

8. Author 1. Surname, Initials	9a. Author 2	9b. Authors 3, 4	10. Date	Pages	Refs.
Cripps, M.N.			December 1991	29	
11 Contract Number	**12. Period**	**13. Project**	**14. Other Reference Nos.**		

15 Distribution statement

(a) Controlled by – Head of Aerodynamics Department

(b) Special limitations (if any) –

If it is intended that a copy of this document shall be released overseas refer to RAE Leaflet No.3 to Supplement 6 of MOD Manual 4.

16. Descriptors (Keywords) (Descriptors marked * are selected from TEST)

Low speed wind tunnel. Aerodynamic test facility

17 Abstract

This paper describes the DRA (Aerospace Division) 13ft x 9ft (4m x 2.7m) Low Speed Tunnel at RAE Bedford. It is intended to provide an introduction to the capabilities of this comprehensive test facility for speeds of up to 90 ms^{-1} at atmospheric pressure